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# An Antenna Design for the Miniaturization of the RFID Tag

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**Abstract**

A novel matching way between antenna of a 2.45GHz active RFID tag and power amplifier (PA) is presented in this paper. Dipole antenna is not only used as a transmitting antenna of the RFID tags, but also as a differential amplifier resonant inductor. The total PA chip size is reduced greatly to only 240μm×70μm in a 0.18μm CMOS process due to saving two on-chip integrated inductors. The total tag size is reduced greatly to only 42mm×18mm owing to meandered dipole antenna.

***Keywords:*** RFID; miniaturization; dipole antenna; power amplifier (PA).

## 1. Introduction

Radio frequency identification (RFID) is a non-contact automatic identification technology, which uses radio frequency for non-contact two-way communication so as to achieve automatic target recognition and access to relevant data. Compared with other means of identification, the technology has better recognition accuracy, higher speed, the ability to adapt to different environment and many other advantages. As an important part of the RFID system, antenna has important theoretical and practical significance. At present, the RFID tag antenna research mainly includes impedance matching technology between tag antenna and the chip, frequency band extension technology and the special antenna design for different complex environment [1-4]. But the research between tag antenna and the internal circuit of the chip is relatively less.

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In addition, active tags have an on-tag power supply and actively send RF signals through power amplifier (PA) for communication, thus RFID tag with power amplifier is a good solution for improving identification distance. Many fully-integrated CMOS PAs have been developed. But many On-chip RF inductors are used in the designs [5-6]. While on-chip RF inductor always occupies very large size, manufacturing cost will suffer a corresponding increase as a result. Some other PAs take advantage of off-chip inductors and get good performance [7-8], but integration density is reduced.

This paper demonstrates a novel antenna design, using PCB antenna as resonant inductor of the PA circuit. Based on this kind of structure, the use of on-chip RF inductors is avoided, which enables the size of the tag chip to be reduced significantly. Simultaneously, the use of meandered dipole antenna can reduce the total tag size dramatically. Moreover, only differential PA can output to dipole antenna directly. Finally, the antenna was fabricated and measured. The measured and simulated results are in good agreement. The PA was fabricated in 0.18μm 1P6M CMOS process. Measurements show that it satisfies EPC global Class-1 Gen-2 with a lineal output power 8dBm.

## 2. System Design

This paper proposes a kind of 2.45GHz active RFID dipole tag antenna. Different from the general dipole antenna, this kind of RFID tag antenna is dual pole antenna, which is an innovative application. It not only can be used as the transmitting antenna of the RFID tag, but also can be used as differential amplifiers resonant inductance. The PA system design is shown in Fig. 1.

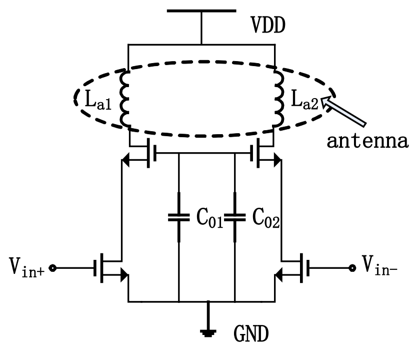


**Figure 1:** The PA system design

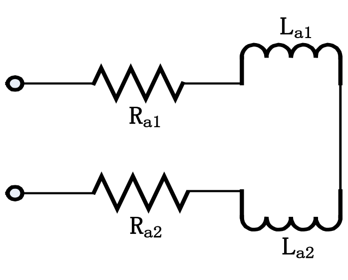


**Figure 2:** Equivalent circuit of the proposed antenna

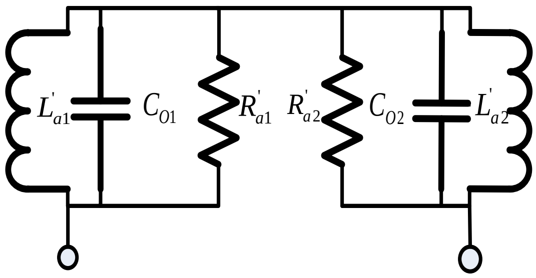


**Figure 3:** Equivalent RLC resonant circuit

The equivalent circuit of the antenna is given in Fig.2, La1 and La2 is equivalent inductance, Ra1 and Ra2 is equivalent radiation resistance. Together with the on-chip capacitor CO1 and CO2, they form RLC resonant circuits. Fig.3 shows equivalent RLC resonant circuit. Assume La1= La2= La, Ra1=Ra2=Ra, CO1=CO2=CO, $R_{a1}' = R_{a2}' = R_a'$, $L_{a1}' = L_{a2}' = L_a'$, Conversion relationship of each component values are as follows:

$$R_a' = R_a \times (Q_{RLC}^{\ 2} + 1) \quad (1)$$

$$L_a' = L_a \times (\frac{Q_{RLC}^{\ 2} + 1}{Q_{RLC}^{\ 2}}) \quad (2)$$

$Q_{RLC}$ represents the Q value of the resonant circuit.

$$Q_{RLC} = \frac{R_a'}{\sqrt{L_a'/C_o}} \quad (3)$$

The maximum output power $P_{OUT\max}$ of the PA is determined as follows by load impedance $R_a'$ and the supply voltage $V_{DD}$.

$$P_{OUT\max} = \frac{V_{DD}^{\ 2}}{2R_a'} \times 2 \quad (4)$$

The reactance $X_a$ of the antenna is determined as follows by the inductance $L_a$ and the resonant frequency $f$.

$$X_a = 2\pi f \times L_a \quad (5)$$

Output power of the PA in the active tag is much smaller than output power of the PA in the reader. The maximum output power of the tag power amplifier is designed for 10mW with the supply voltage of 1.8V in this paper. To work at 2.45GHz and obtain an appropriate $Q_{RLC}$, the La of 5nH is designed. The unilateral reactance Xa of the antenna is 77 $\Omega$, which can be calculated from (5). The on-chip capacitance is 650fF in consideration of parasitic capacitance. Ra is 28 $\Omega$ for the expected maximum total output power of PA. Therefore, the input impedance of the antenna is $56+j154(\Omega)$ through theoretical analysis.

### 3. Structure and Design

The PCB antenna presented in this paper is divided into two layers . The top layer is the antenna model and the bottom layer is constituted by welding copper and the insulated wire. The top metal and the pads on the bottom layer are connected by the vias. When testing the antenna, we need to externalize some necessary circuit or probe, which is the function of welding copper pads. But copper pads seriously affect the performance of the antenna. To reduce the impact on antenna impedance, copper pads are placed on the other side of the PCB.

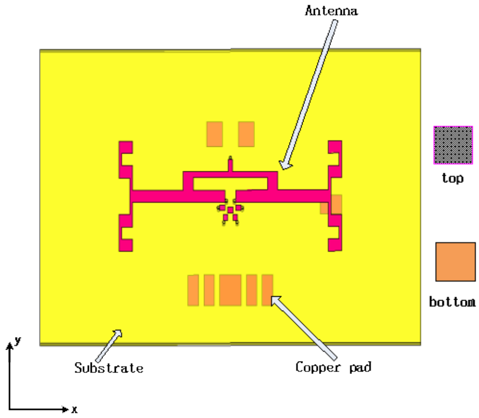


**Figure 4:** a. 3D pattern of the proposed antenna

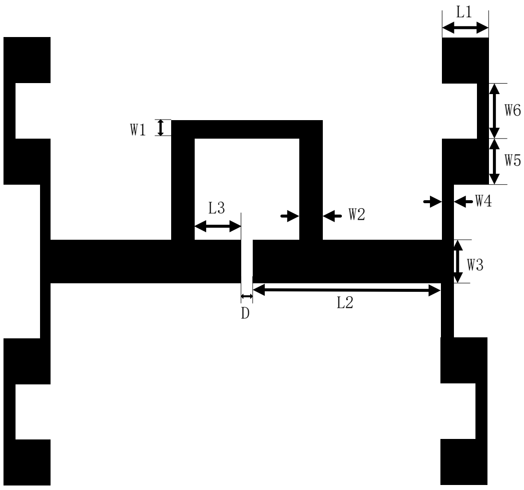


**Figure 4:** b. Top view of the proposed antenna

The structure of the proposed antenna is illustrated in Fig.4.a. The antenna is composed of a T-matching network added on the port and the meander dipoles, which are used to reduce the size of the dipole antenna and a Duroid substrate $(h=1mm, \varepsilon_r=2.2, \tan\delta=0.0009)$. The overall size of the antenna is $42\times18\times1mm^3$. The antenna shown in the Fig.4.b was previously designed and tested to confirm the simulations performed in this study. The purpose of using a T-matching network is to realize high reactance that is the requirement of PA, and the T-matching network is just a kind of method which can realize the high impedance antenna. So the T-matching network is mainly designed according to the impedance characteristics of the PA. L3 is the length of the T-matching network and it is a critical parameter. It mainly affects the real part of the antenna impedance. The bending radiator is to ensure the antenna's electrical length unchanged and try to reduce its physical length so as to achieve the miniaturization of the antenna. However, it will reduce the gain of the antenna and increase ohmic losses of the antenna. Therefore, we should find a balance point in the design of the antenna. The length of bending radiator is mainly determined by the resonant frequency. The wavelength is 122mm when the resonant frequency is 2.45GHz. The total length of the bending radiator is 67mm, which is nearly the half of the wavelength. L2, the distance between the feeding point and bending radiator, is also a critical parameter. It mainly affects the imaginary part of the antenna impedance. Other parameters in the antenna mainly influence the resonant frequency, so we can use them to fine-tune the resonant frequency of the antenna.

Eventually, the proposed antenna is simulated to have a good agreement between itself and PA. Also, some spaces among the T-matching network are reserved for tuning the T-matching network to get an impedance matching in the case of other PA. The meander dipole antenna instead of differential amplifiers resonant inductance greatly reduces the whole size of the RFID tag.

**4. Simulation**

Ansoft HFSS v13 electromagnetic simulation software is used for simulation and optimization. The optimization of antenna parameters is to make antenna performance better, but also to meet the requirements of the PA on the impedance, at the same time, miniaturized antenna as much as possible.

Fig. 5 shows the return loss of the PCB antenna. The resonant frequency of the antenna is 2.45GHz, the S11 of the resonance point is -50.9607dB and -10dB bandwidth of the antenna is about 1GHz. The real part of the antenna impedance varies with L3, while the imaginary part of the antenna impedance varies with L2, as shown in Fig.6 and Fig.7. Meanwhile, when the appropriate parameters can be obtained, the impedance of the antenna can approach $56+j154(\Omega)$, which can achieve a perfect match with the PA, as shown in Fig.8. The antenna specific design dimensions are shown in Table 1.a and Table 1.b. Fig.9 shows the radiation patterns of the proposed antenna at 2.45GHz. It can be seen that the radiation patterns of the antenna are in the range of θ from -90° to 90°, which means omni - directional antenna. Fig.10 shows the maximum gain of the antenna is in the negative direction of the y-axis and the maximum gain is 1.71dBi.

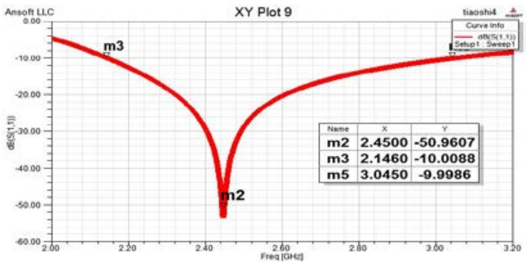


**Figure 5:** The simulated results of return loss for the optimized antenna

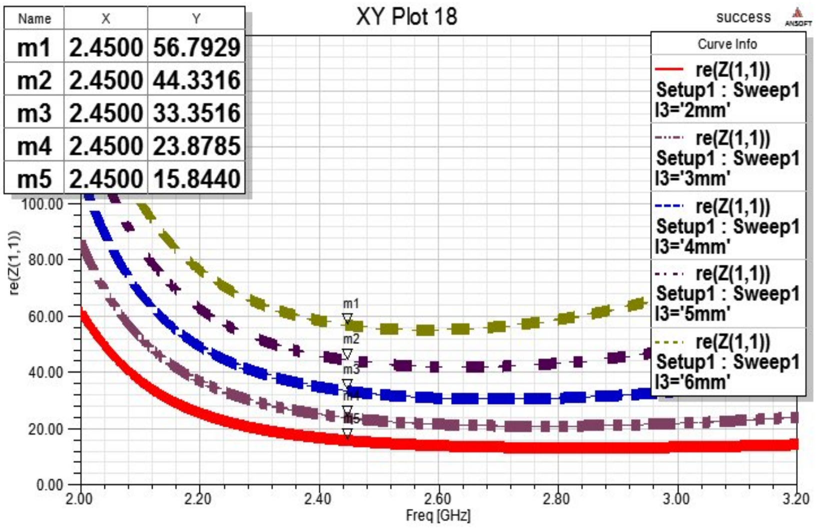


**Figure 6:** The real part of the impedance varies with L3

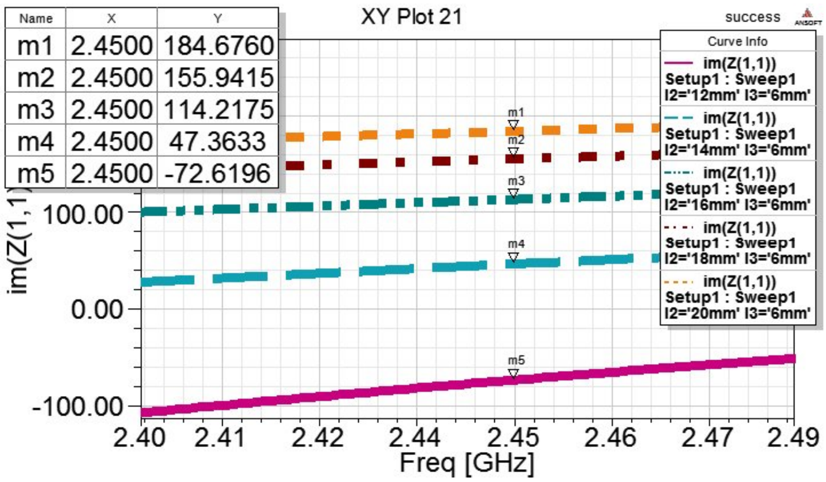


**Figure 7:** The imaginary part of the impedance varies with L2

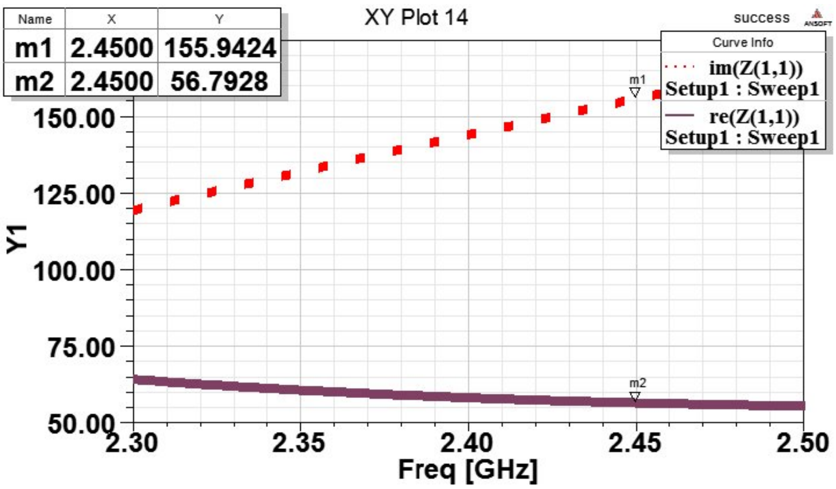


**Figure 8:** The antenna impedance at 2.45GHz

**Table.1.a:** The antenna specific design dimensions

| L1 | L2 | L3 | W1 | W2 |
|---|---|---|---|---|
| 2.5mm | 17.5mm | 6.0mm | 1.0mm | 1.9mm |

**Table.1.b:** The antenna specific design dimensions

| W3 | W4 | W5 | W6 | D |
|---|---|---|---|---|
| 2.5mm | 0.5mm | 2.0mm | 2.0mm | 2.0mm |

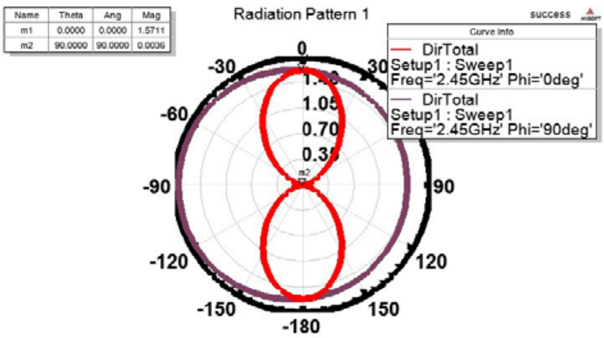


**Figure 9:** The radiation patterns of the antenna

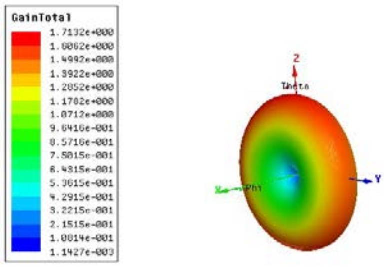


**Figure 10:** The 3D Polar Plot of the antenna

**5. Test and Discussion**

The chip is directly glued to the PCB board using an electrically and thermally conductive adhesive. The pads were wire bonded to the gold-plated metal lines on the PCB. The test-site of tag transmitter chip and the PCB of tag transmitter chip are shown in Fig. 11 and Fig. 12. As shown in Fig.11, SUING SS1792C (dc stable power) supply 1.8V power supply voltage for the test board, Tektronix connects to the enable of the chip. R&S FSL18 monitors transmitter output signal spectrum and power spectrum analyzer features. Due to reduce two on-chip integrated inductors, changes in chip size are obvious, as shown in Table 2. Furthermore, the dipole bending technology can make the antenna size down to 42mm×18mm, which is helpful for the miniaturization of RFID tags.

Working frequency of the PCB antenna is measured by Agilent E5070B, as shown in Fig. 13 and we can see that the working frequency of the PCB antenna is -38.60dB, which is different from the simulation frequency in HFSS. Owing to the SMA connector, in high frequency there is some current loss caused by the coaxial cable, so the measured results differ a little from the simulated results. Moreover, compared with previous simulation results, -10dB bandwidth of the antenna is narrow. The reason is that the surrounding conductors, such as copper pads on the other side of the PCB, have effect on the tested antenna. The unilateral antenna on the radiation impedance gain power is 2.91 dBm, as shown in Fig.14. Considering 2 dB power loss of the cable, the total dipole antenna radiation power is about 7.91 dBm $(2.91dBm + 3dBm + 2dBm = 7.91dBm)$. Meanwhile, the center frequency of the output signal is 2.42GHz, which is slightly lower compared with the designed value. This may be the parasitic effects of the parasitic inductance of a bonding wire. The measured output power of the PA is shown in Fig.15, with a supply voltage of 1.8V and gate bias voltages of 0.6V, the PA provides output P1dB of 8dBm. The post layout simulated results are also illustrated in Fig.15. The difference between the measured and simulated power is 5dBm, which appears to result from insufficient accuracy of RF transistor models and transmission loss.

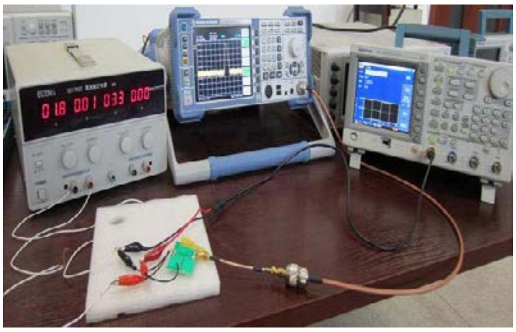

**Figure 11:** Test-site of tag transmitter chip

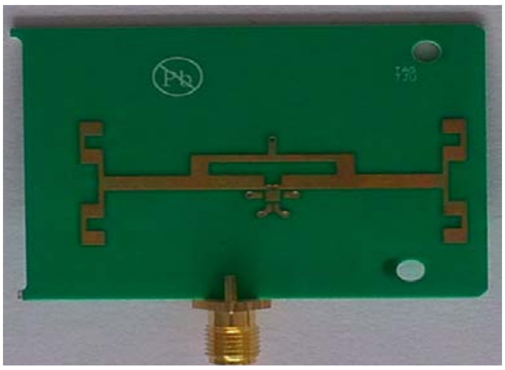

**Figure 12:** a. The PCB of tag transmitter chip

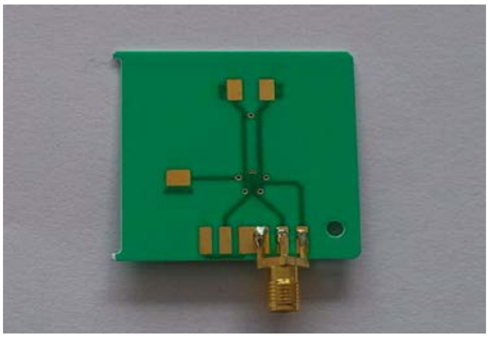

**Figure 12:** b The back of tag transmitter chip

**Table 2:** Integrated inductor on the chip size

| | On-chip inductors | Off-chip inductors |
|---|---|---|
| Size | 460×80um$^2$ | 240×70um$^2$ |

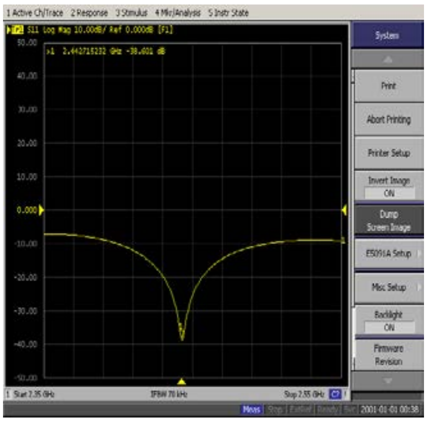


**Figure 13:** S11 of the tested PCB antenna

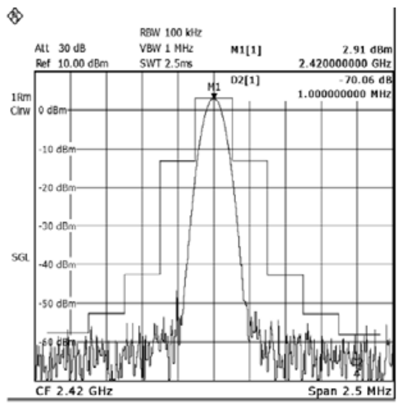


**Figure 14:** The radiation impedance gain power

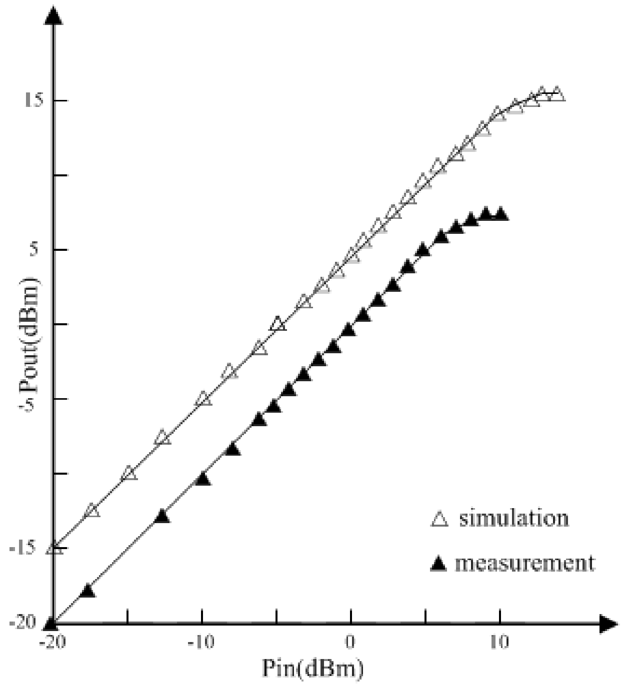


**Figure 15:** Measured and simulated output power

## 6. Conclusion

In this paper, a 2.45GHz active RFID dipole tag antenna and a new matching way between PA and antenna are established. Associated with the design of PCB antenna, on-chip RF integrated inductors are not used. The total chip size is also reduced greatly to only 240μm× 70μm. The size of the total RFID tag also reduced greatly to only 42mm× 18mm. The antenna was fabricated and measured and the results are in good agreement.

## References


[1] Wonkyu Choi, Son, H. w, Chansoo Shin, Ji-Hoon Bae, Gilyoung Choi, RFID tag antenna with a meandered dipole and inductively coupled feed. Antennas and Propagation Society International Symposium. C. IEEE, **9-14,** 619-622 (2006).

[2] Li Yang，Serkan Basat，Amin＆da，and Manos M．Tentzeris, Design and Development of Novel Miniaturized UHF RFID Tags on Ultra-low-cost Paper-based Substrates, Microwave Conference. C. APMC, Asia-Pacific, **12-15**, 1493-1496 (2006)

[3] G. Marrocco, “The Art of UHF RFID Antenna Design: Impedance-matching and Size-reduced Techniques,” IEEE Trans. Antennas Propag. J. **50**, 66-79 (2008).

[4] S. W. Bae, W. Lee, K. Chang, S. Kwon, and Y. J. Yoon, “A Small RFID Tag Antenna with Bandwidth-enhanced Characteristic and A Simple Feeding Structure,” Microwave Opt. Tech. Lett.J. **50**, 2027-2031 (2008).

[5] Yongbing Q, Wenyuan L, Zhigong W, 2.4-GHz 0.18-μm CMOS highly linear Power Amplifier: Advanced Technologies for Communications (ATC). C. (2010).

[6] Li Stanley Y. Y. Leung and David C. C. Lam, Performance of Printed Polymer-Based RFID Antenna on Curvilinear Surface, IEEE Transactions On Electronics Packaging Manufacturing. J. **30**, (2007).

[7] Sowlati T, Leenaerts D, A 2.4GHz 0.18μm CMOS self-biased cascode power amplifier with 23dBm output power, Solid-State Circuits Conference, 2002. Digest of Technical Papers. C. (2002).

[8] Jian F, Shilei H, Yumei H, et al, A 2.4G-Hz CMOS Power Amplifier: Solid-State and Integrated Circuit Technology (ICSICT). C. (2010).